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(54) **Generating rotational speed data for an internal combustion engine**

(57) A rotational speed data generator obtains engine speed data wherein the pulsating component in the speed of an i.c. engine is eliminated. The data generator has a rotational speed sensor outputting a pulse every predetermined rotational angle of a crank shaft of the engine, a circuit for obtaining period data representing the period of generation of the pulse, a circuit responsive to the period data for computing average speed data, a circuit for computing the rate of change with time of the engine speed on the basis of the average speed data, and a circuit for obtaining engine speed data by amending the average speed data according to the rate of change to correct an error of the engine speed represented by the average speed data. Therefore, stable control of the operation of the engine can be realized without degrading the response characteristics by using the engine speed data obtained from the data generator.

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The drawings originally filed were informal and the print here reproduced is taken from a later filed formal copy.

FIG. 1

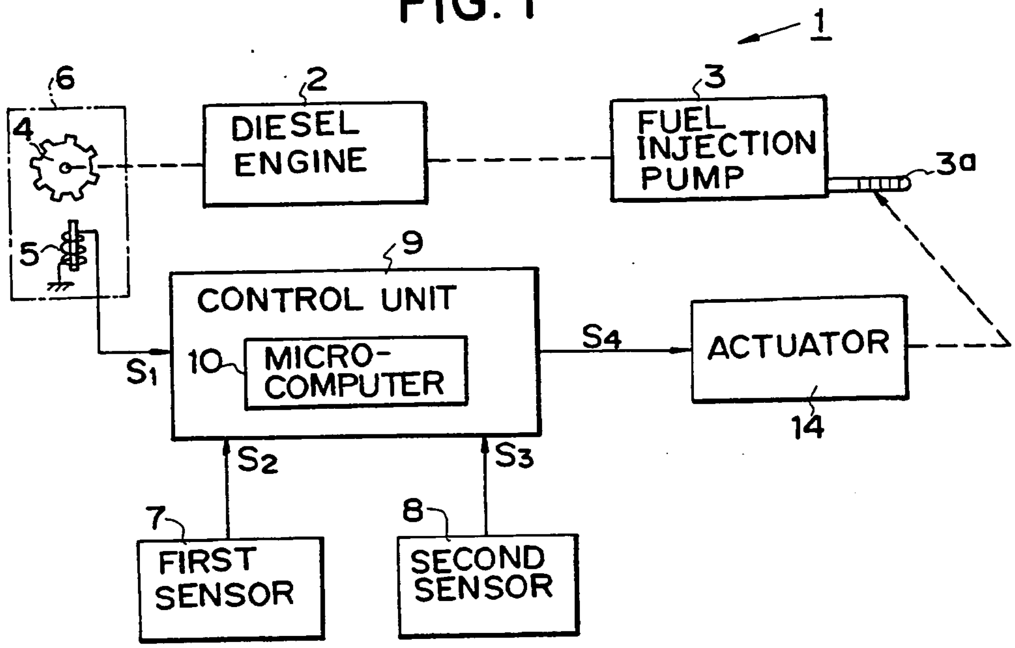


FIG. 2A

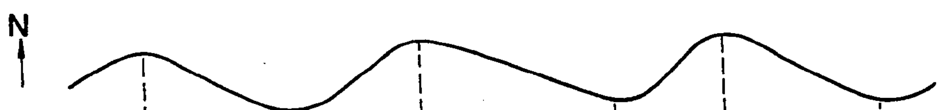


FIG. 2B

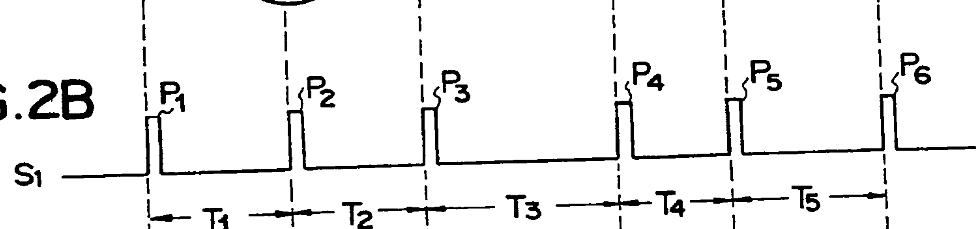


FIG. 2C

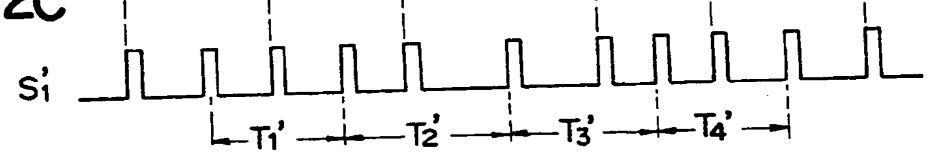


FIG. 3

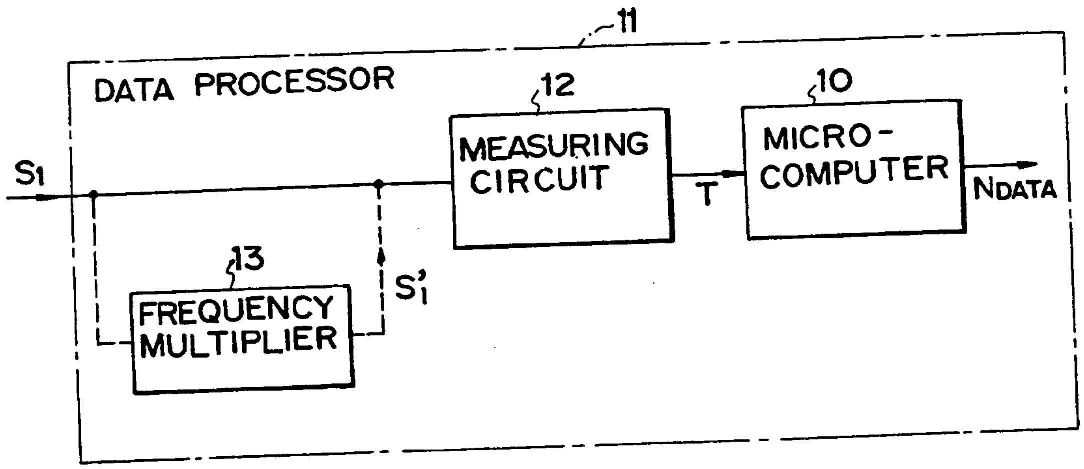


FIG. 7A

FIG. 7B

FIG. 7C

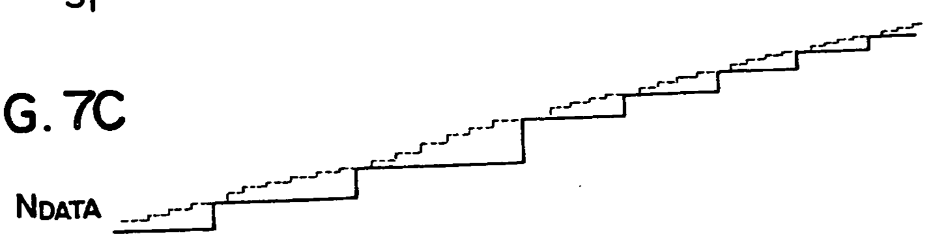


FIG.4

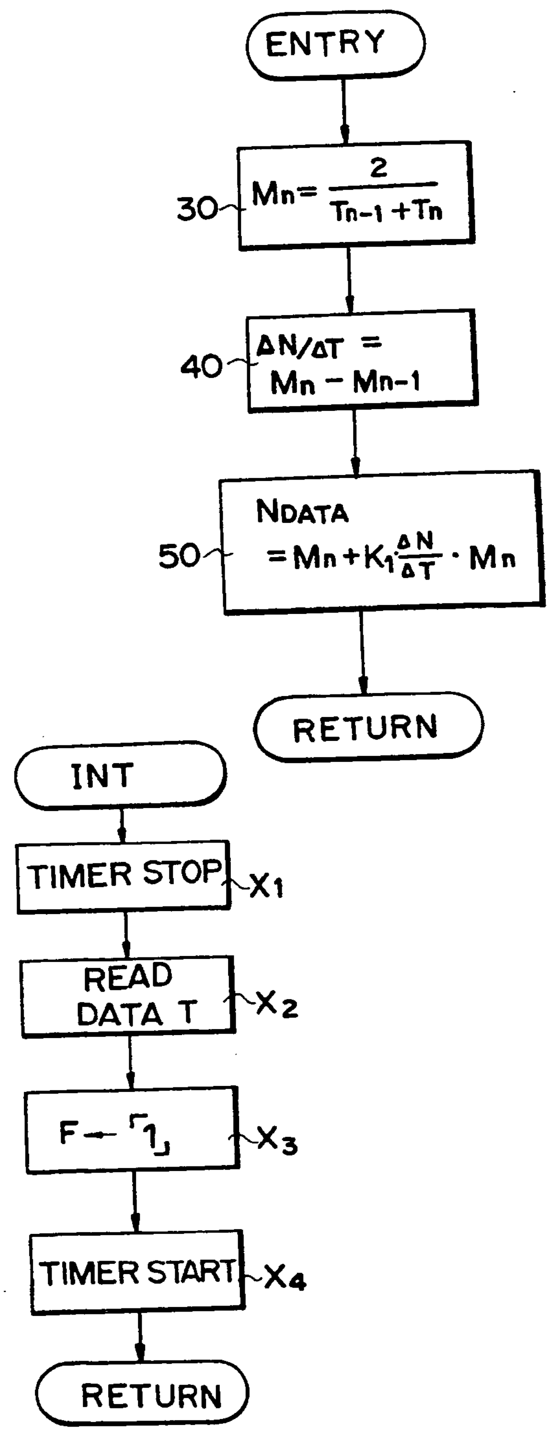

ENTRY
30 Mn = 2 / (Tn-1 + Tn)
40 ΔN/ΔT = Mn − Mn-1
50 NDATA = Mn + K1·ΔN/ΔT · Mn
RETURN
INT
TIMER STOP X1
READ DATA T X2
F ← 「1」 X3
TIMER START X4
RETURN

FIG.5

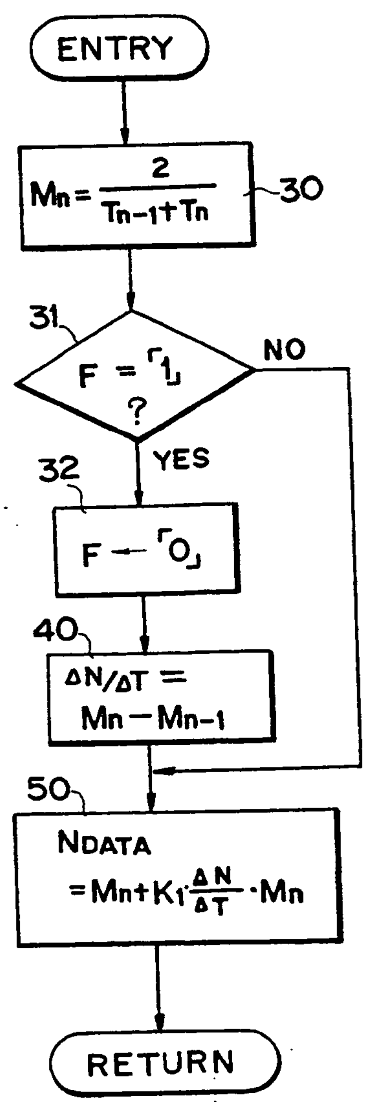

ENTRY
Mn = 2 / (Tn-1+Tn) 30
31 F = 「1」 ?
NO
YES
32 F ← 「0」
40 ΔN/ΔT = Mn − Mn-1
50 NDATA = Mn+K1·ΔN/ΔT ·Mn
RETURN

FIG.6

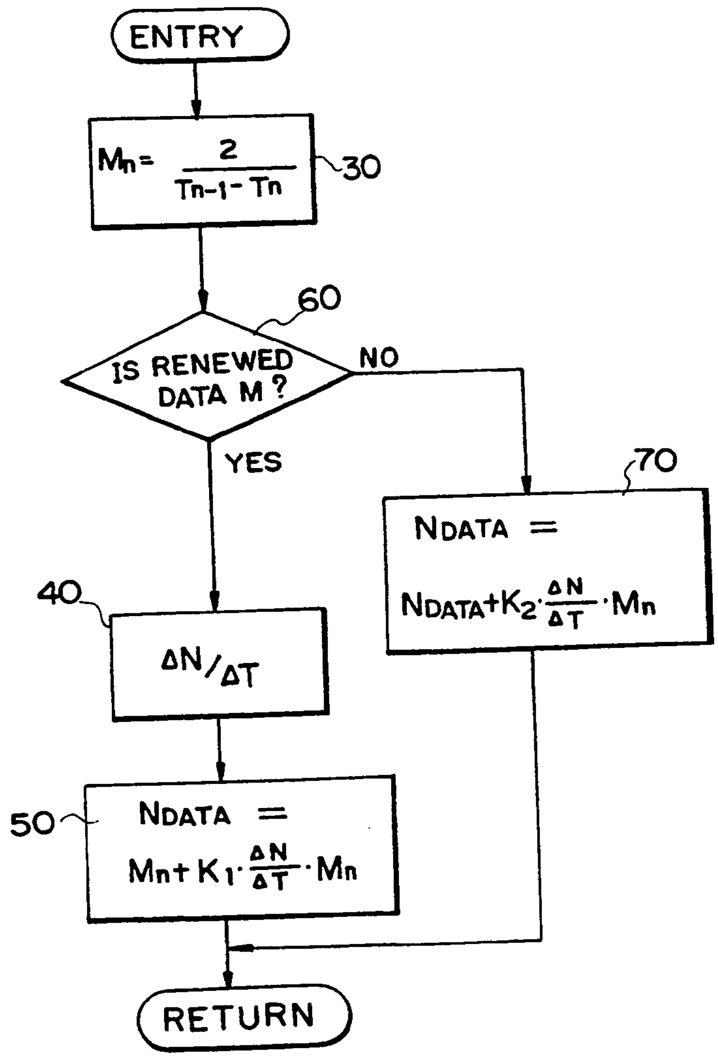
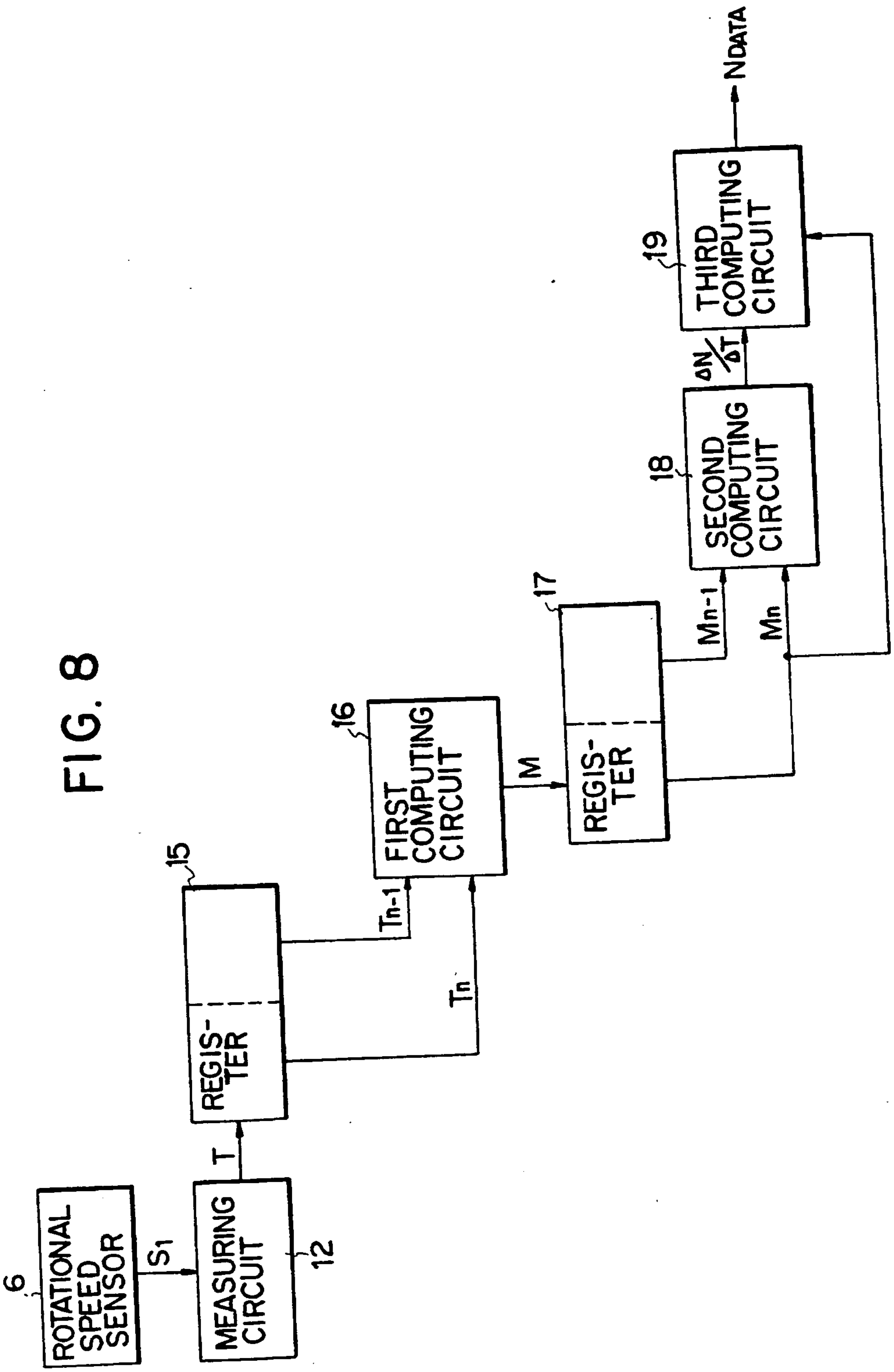

ENTRY
$M_n = \frac{2}{T_{n-1} - T_n}$
30
60
IS RENEWED DATA M ?
NO
YES
70
$N_{DATA} = N_{DATA} + K_2 \cdot \frac{\Delta N}{\Delta T} \cdot M_n$
40
$\Delta N / \Delta T$
50
$N_{DATA} = M_n + K_1 \cdot \frac{\Delta N}{\Delta T} \cdot M_n$
RETURN

FIG. 8


ROTATIONAL SPEED SENSOR
6
S1
MEASURING CIRCUIT
12
T
REGIS-TER
15
Tn-1
Tn
FIRST COMPUTING CIRCUIT
16
M
REGIS-TER
17
Mn-1
Mn
SECOND COMPUTING CIRCUIT
18
ΔN/ΔT
THIRD COMPUTING CIRCUIT
19
NDATA

SPECIFICATION

Apparatus for generating rotational speed data for an internal combustion engine

This invention relates to an apparatus for generating rotational speed data for an internal combustion engine, and more particularly to an apparatus for generating rotational speed data for an internal combustion engine suitable for obtaining rotational speed data for supply to an electronic speed regulator of the internal combustion engine.

In general, it is necessary to electrically detect the rotational speed of an internal combustion engine to control the operation of the internal combustion engine electronically. The rotational speed data used for this purpose is one of the most important types of data for electronic control of the operation of an internal combustion engine and it is desired to obtained data which accurately represents the actual instantaneous rotational speed for improving the control acuuracy.

The conventional rotational speed data generator which has heretofore been used for this purpose is so arranged that a rotational speed sensor for generating an electrical pulse upon each rotation of the crank shaft of the engine by a predetermined angle is provided so that the rotational speed of the internal combustion engine is detected from the period of the pulse train signal generated from the sensor (e.g. Japanese Laid Open Patent Publication No. 171047/82).

However, a problem arises when an attempt is made to conduct operational control of the internal combustion engine with high accuracy by using the rotational speed data obtained by the conventional rotational speed data generator. the internal combustion engine effects intake, compression, power and exhaust strokes in a given cycle and the speed of the internal combustion engine pulsates periodically because of fluctuations in the angular velocity of the crank shaft caused by the power strokes of the respective pistons. For this reason, when the rotational speed data obtained by the conventional rotational speed data generator is used as it is to regulate the speed of the engine, it is not possible to assure stable operation of the engine and accurate speed control thereof. On the other hand, if the detected data is averaged to eliminate the pulsating component arising in the rotational speed data, there is produced a difference between the rotational speed represented by the average data and the actual rotational speed. Such data, if used for control of the engine, will cause hunting in the operation of the engine speed control and render the control unstable.

It is, therefore, an object of the present invention to provide an improved apparatus for generating rotational speed data for an internal combustion engine.

It is another object of the present invention to provide an apparatus for generating rotational speed data which is capable of producing precise engine speed data suitable for electronically controlling the operation of the internal combustion engine stably without degrading the response characteristics.

According to the present invention, in a rotational speed data generator which generates engine speed data representative of the rotational speed of an internal combustion engine, the rotational speed data generator comprises a rotational speed sensor outputting a pulse every predetermined rotational angle of a crank shaft of the internal combustion engine, means for obtaining a period data representing the period of generation of the pulse in response to a pulse train signal comprised of the pulses, means responsive to the period data for computing an average speed data representing the average speed of the internal combustion engine, means for computing a rate of change with time of the engine speed on the basis of the average speed data, and means for obtaining an engine speed data by amending the average speed data according to the rate of change to corect an error of the engine speed represented by the average speed data.

The invention will be better understood and the other objects and advantages thereof will be more apparent from the ensuing detailed description of a preferred embodiment. taken in conjunction with the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a block diagram of one form of a Diesel engine system provided with a rotational speed data generator of the present invention;

Figure 2A is a graph showing the change in the rotational speed of the Diesel engine;

Figure 2B is the waveform of the pulse train signal of Fig. 1;

Figure 2C is the waveform of the frequency multiplied pulse train signal of Fig. 3;

Figure 3 is a block diagram of a data processor;

Figure 4 is a flow chart of a program for obtaining instantaneous rotational speed data, which is stored in the microcomputer shown in Fig. 3;

Figure 5 is a flow chart of another program for obtaining instantaneous rotational speed data in accordance with the present invention;

Figure 6 is a flow chart of still another program for obtaining instantaneous rotational speed data in accordance with the present invention;

Figure 7A is a graph showing the change in the rotational speed of the Diesel engine;

Figure 7B is the waveform of the pulse train signal obtained in response to the rotational speed shown in Fig. 7A;

Figure 7C is a view showing the change in rotational speed data; and

Figure 8 is a block diagram of another embodiment of the rotational speed data generator of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Fig. 1 schematically shows a block diagram of one form of a Diesel engine system provided with a rotational speed data generator embodying the present invention. The Diesel engine system 1 comprises a Diesel engine 2 and a fuel injection pump 3 for injecting and supplying fuel into the Diesel engine 2. The crank shaft (not shown) of the Diesel engine 2 has a conventional rotational speed sensor 6 comprises of a gear plate 4 and an electromagnetic pick-up coil 5. The rotational speed sensor 6 outputs a pulse train signal S_1 formed of pulses generated one for every predetermined angle of rotation of the crank shaft. The Diesel engine system 1 further comprises a first sensor 7 for producing a first signal S_2 representative of the amount of operation of an accelerator pedal and a second sensor 8 for producing a second signal S_3 representing the temperature of the engine coolant of the Diesel engine 2. The pulse train signal S_1 and the first and the second signal S_2 and S_3 are input to a control unit 9 having a microcomputer 10. In response to these input signals, the control unit 9 generates a control signal S_4 for positioning a fuel adjusting member 3_a for controlling the amount of fuel injected and the control signal S_4 is applied to an actuator 14 to which the adjusting member 3_a is connected. Thus, the amount of fuel injected is controlled in accordance with the control signal S_4 and the operation control of the internal combustion engine is effected electronically according to a desired governor characteristic.

As the arrangement for controlling the amount of fuel injected in response to the input signals as described above is known, a detailed description thereof is omitted here.

As described above, since the rotational speed of the Diesel engine 2 contains a periodically fluctuating component, the instantaneous rotational speed N shows a substantially sinusoidal fluctuation as illustrated in Fig. 2A. As a result, time intervals T_1, T_2, T_3, . . . at which the pulses P_1, P_2, P_3 . . . making up the pulse train signal S_1 output from the rotational speed sensor 6 are generated also fluctuate periodically (Fig. 2B).

To eliminate the influence of the pulsating component appearing in the pulse train signal S_1 and to produce instantaneous rotational speed data of the actual rotational speed of the engine on the basis of the pulse train signal S_1, the pulse train signal S_1 is processed by a data processor 11 (refer to Fig. 3) including the microcomputer 10 provided within the control unit 9.

Fig. 3 is a block diagram of the data processor 11. The pulse train signal S_1 is input to a measuring circuit 12 for measuring the period of the signal S_1 and the time intervals T_1, T_2, T_3, . . . of generation of the pulses P_1, P_2, P_3, . . . comprising the pulse train signal S_1 as shown in Fig. 2B are sequentially measured upon each generation of a pulse. The resultant period data T indicating the result of the measurement is input to the microcomputer 10 sequentially. The microcomputer 10 stores a program for computing engine speed data N_{DATA} based on the period data T input thereto sequentially. The instantaneous engine speed data N_{DATA} is computed in accordance with the program in synchronization with the generation of the pulses of the pulse train signal S_1.

Fig. 4 shows a flow chart of one example of the program for computing the instantaneous engine speed data N_{DATA}. The program shown in Fig. 4 is executed in synchronization with the pulse train signal S_1. At step 30, average speed data M_n of the Diesel engine 2 at the time the data T_n is produced is computed according to the following formula:

$$M_n = \frac{2}{T_{n-1} + T_n} \qquad (1)$$

where T_n is the period represented by the period data T determined by the present measurement by the measuring circuit 12 and T_{n-1} is the period represented by the period data T determined by the preceding measurement. Thus, there is obtained data representing the average engine speed in which the influence of the periodic pulsating component in the rotational speed of the engine is reduced. The value of the engine speed represented by the average speed data M substantially corresponds to the average value of the rotational speed N shown in Fig. 2A.

After the value M_n of the average speed data M is obtained, the variate $\Delta N/\Delta T$ of the engine speed per unit time is computed at step 40 on the basis of the difference between the value M_n

of the presently obtained average speed data M and the value M_{n-1} of the average speed data M obtained one step earlier. In short, the variate $\Delta N/\Delta T$ is computed as follows:

$$\Delta N/\Delta T = M_n - M_{n-1} \qquad (2)$$

The value of $\Delta N/\Delta T$ is multiplied by a constant K_1 and the value of M_n of the average speed data M and the resultant product is added to the value M_n of the average speed data M to obtain final engine speed data N_{DATA} (step 50).

That is, in step 50, engine speed data N_{DATA} is computed in accordance with the following formula:

$$N_{DATA} = M_n + K_1 \cdot \frac{\Delta N}{\Delta T} \cdot M_n \qquad (3)$$

With this arrangement, although the value of the average speed data M obtained at step 30 is an average value and contains a delay factor, the delay factor caused by the average value can be eliminated by adding $K_1 . \Delta N/\Delta T . M_n$ as a value associated with the time differential amount of the engine speed. Thus, there can be obtained rotational speed information free from the pulsating component of the engine speed and without delay from the actual rotational speed of the engine, so that stable and precise control of the amount of fuel injected can be effected without causing hunting in the rotation of the engine by conducting the control of the amount of fuel injected using the engine speed data N_{DATA}.

Fig. 5 shows a modification of the program shown in Fig. 4. The program of Fig. 5 is a program for executing an operation for obtaining the speed data N_{DATA} asynchronously with the pulse train signal S_1. In this case, an interrupt program INT is executed in response to the output of the pulses of the pulse train signal S_1. This interrupt program INT executes, upon the generation of each pulse comprising the pulse train signal S_1, the operations of stopping a timer (step x_1), reading in new period data T from the measuring circuit 12 (step x_2), setting a flag F for indicating that the new period data is read in (step x_3), then starting the timer when the succeeding pulse is output (step x_4) and returning to the main program (not shown).

The program for computing the engine speed data N_{DATA} is a program which is formed of the program shown in Fig. 4 and steps 31 and 32 added thereto. After completion of the execution of step 30, whether the flag F has been set or not is discriminated at step 31. If the flag F has been set, the flag F is reset (step 32) to advance to step 40. If the flag F has not been set, i.e., if the value of the period data T is not renewed, step 40 is omitted and step 50 is executed. In other words, in case of an asynchronous type program wherein the program for computing the engine speed data N_{DATA} is executed asynchronously with the pulse train signal S_1, whether the period data T has been renewed or not is always monitored by the flag F and only when the period data T has been renewed, step 40 is executed and otherwise the execution of step 40 is omitted.

Since the value of the engine speed data N_{DATA} is renewed upon the generation of each pulse of the pulse train signal S_1 in the foregoing porgrams, there is a tendency for the difference between the actual rotational speed and the rotational speed indicated by N_{DATA} to be enlarged, and high proportion control cannot be expected in the low speed rotational range of the engine.

Fig. 6 shows the flow chart of an example of a program which can reduce the difference between the actual rotational speed and the rotational speed indicated by N_{DATA} even if the engine speed is relatively low. In the flow chart of Fig. 6, the same steps as in the basic flow chart of Fig. 4 are denoted by the same reference numbers. In the flow chart of Fig. 6, step 60 which discriminates whether or not the value of the average speed data M has been renewed is provided between step 30 and step 40. Only when the result of the discrimination at step 60 is NO, the procedure advances to step 70 and the engine speed data N_{DATA} is renewed every program cycle using the value of $\Delta N/\Delta T$ even if there is no renewal of the average speed data M.

More specifically, when a pulse P_n of the pulse train signal S_1 is output, the new value M_n of the average speed data M is computed at step 30. As a result, the result of the discrimination at step 60 becomes YES so that the computation of $\Delta N/\Delta T$ (step 40) is executed and correction by addition of the differential amount at step 50 is carried out to obtain the instantaneous rotational speed data N_{DATA} indicating the engine speed at that time. In the succeeding program cycle, if the succeeding pulse P_{n+1} of the pulse train signal S_1 has not been output, the result of the discrimination at step 60 becomes NO and step 70 is executed. In step 70 the value of $\Delta N/\Delta T$, which is obtained by the computation when the pulse P_n is output, is multiplied by a constant K_2 and the value M_n of the average speed data M, and the product of the muliplication is added to N_{DATA} to obtain new N_{DATA}. Thus, the rate of change in the rotational speed of the engine is obtained from the value $\Delta N/\Delta T$ so as to stepwisely change the engine speed data N_{DATA} every

program cycle in accordance with the rate of change in the period before the succeeding average speed data value M_{n+1} is applied.

When the calculation of the engine speed data N_{DATA} is carried out as described above, under the condition that the engine speed N is varied as shown in Fig. 7A and the pulse train signal S_1 appears as shown in Fig. 7B, the obtained value of the data N_{DATA} is as shown by the solid line in Fig. 7C according to the program of Fig. 4. However, under the same conditions as described above, according to the program of Fig. 6, the value of the data N_{DATA} obtained at the time of generation of each pulse of the pulse train signal S_1 is amended based on the value of $\Delta N/\Delta T$ upon each execution of the program as described above so that the value of N_{DATA} becomes as shown by the broken line in Fig. 7C. Therefore, when the engine is in the low speed range, any large discontinuity in the value of the data N_{DATA} can be suitably interpolated so as to assure smooth control of the amount of fuel injected and contribute to stabilization of the control system.

Although step 70 is provided in the program of Fig. 6 to reduce the influence of the stepwise change in the data N_{DATA} value on the control system, a frequency multiplier 13 may alternatively be provided on the input side of the measuring circuit 12 as shown by the dotted line in Fig. 3 to obtain a frequency multiplied signal S_1' having, for example, twice as may pulses as those (i.e. a frequency double the frequency) of the pulse train signal S_1 as shown in Fig. 2C so as to increase the number of pulses and accordingly to increase the computing frequency of the engine speed data N_{DATA}. In this case, the average speed value DM_1, DM_2, DM_3, . . . may be computed in accordance with the following formulae:

$$DM_1 = \frac{2}{T_1 + T_2},$$

$$DM_2 = \frac{2}{T_1' + T_2'},$$

$$DM_3 = \frac{2}{T_2 + T_3},$$

The factor of frequency multiplication of the pulse train signal S_1 in the frequency multiplier 13 is not limited to two but may be any desired number.

Although the engine speed data obtained by the apparatus for generating rotational speed data according to the present invention is applied to the control of the amount of fuel injected of a Diesel engine in the foregoing embodiments, the present invention is not limited to this embodiment but may also be used to attain rotational speed data of other types of internal combustion engines, such as a gasoline engine. The obtained data may also be used for a purpose other than the control of the amount of fuel injected.

Fig. 8 is a block diagram of another embodiment of the rotational speed data generator of the present invention and the function of this rotational speed data generator corresponds to that of the program shown in Fig. 4.

In Fig. 8, the rotational speed sensor 6 and the measuring circuit 12 are the same as those of Figs. 1 and 3. The period data T from the measuring circuit 12 is applied to a register 15 which is capable of storing the two last period data T_{n-1} and T_n. Data T_{n-1} and T_n are applied to a first computing circuit 16 in which average speed data M is computed on the basis of the above mentioned formula (1) and the two last average data M_{n-1} and M_n are stored in another register 17. These average data M_{n-1} and M_n are applied to a second computing circuit 18 in which the variate $\Delta N/\Delta T$ of the engine speed per unit time is calculated in accordance with the formula (2). The computed result of the second computing circuit 18 and the data M_n are applied to a third computing circuit 19 to compute rotational speed data N_{DATA} in accordance with the formula (3).

According to the present invention, there can be obtained engine speed data wherein the pulsating component in the rotational speed of the internal combustion engine is eliminated and which has no delay from the actual rotational speed of the engine. Therefore, stable control of the operation of the internal combustion engine can be realized without degrading the response characteristics by using the engine speed data obtained by the present invention for the control of the operation of the internal combustion engine.

CLAIMS

1. An apparatus for generating rotational speed data representative of the rotational speed of an internal combustion engine, said apparatus comprising:
a rotational speed sensor for outputting a pulse for each predetermined angle of rotation of the crank shaft of the internal combustion engine;
means for producing period data representing the period of generation of the pulses;
means responsive to the period data for computing average speed data representing the average speed of the internal combustion engine;
means for computing the rate of change with time of the engine speed on the basis of the average speed data; and
means for obtaining engine speed data by correcting said average speed data according to the rate of change to eliminate any error in the engine speed represented by the average speed data.

2. An apparatus as claimed in Claim 1, further comprising a frequency multiplier for obtaining a frequency multiplied signal of the pulse train signal from said rotational speed sensor, the frequency multiplied signal being applied to said period data producing means.

3. An apparatus as claimed in Claim 1 wherein said average speed data computing means computes the average speed data M on the basis of the period data T_n presently produced by said period data producing means and period data T_{n-1} which was produced earlier.

4. An apparatus as claimed in Claim 3 wherein said data T_{n-1} is data produced one cycle of the pulsation in the engine speed before the data T_n was produced.

5. An apparatus as claimed in Claim 3 wherein said rate computing means computes the rate of change $\Delta N/\Delta T$ with time of the engine speed in accordance with the following formula:

$$\Delta N/\Delta T = M_n - M_{n-1}$$

wherein: M_n is the presently produced average speed data M, and
M_{n-1} is average speed data M produced earlier.

6. An apparatus as claimed in Claim 5 wherein the engine speed data N_{DATA} is computed in said engine speed data obtaining means on the basis of the following formula:

$$N_{DATA} = M_n + K_1 . \frac{\Delta N}{\Delta T} . M_n$$

wherein: K_1 is a constant.

7. An apparatus for generating a rotational speed data representative of the rotational speed of an internal combustion engine, said apparatus comprising:
a rotational speed sensor for outputting a pulse for each predetermined angle of rotation of the crank shaft of the internal combustion engine;
a first means for producing period data representing the period of generation of the pulses;
a detecting means for detecting the occurrence of the pulses produced from said rotational speed sensor;
a second means responsive to the period data for computing average speed data representing the average speed of the internal combustion engine;
a third means for computing the rate of change with time of the engine speed on the basis of the average speed data only when said detecting means detects the occurrence of a pulse; and
means for obtaining engine speed data by correcting said average speed data according to the rate of change from said third means to eliminate any error in the engine speed represented by the average speed data every predetermined time interval.

8. An apparatus for generating rotational speed data representative of the rotational speed of an internal combustion engine, said apparatus comprising:
a rotational speed sensor for outputting a pulse for each predetermined angle of rotation of the crank shaft of the internal combustion engine;
means for producing period data representing the period of generation of the pulses;
means responsive to the period data for computing average speed data representing the average speed of the internal combustion engine;
means for discriminating whether or not the average speed data has been renewed;
means for computing the rate of change with time of the engine speed on the basis of the average speed data when it is detected that the average speed data has been renewed by said discriminating means;
means for obtaining engine speed data by correcting said average speed data according to the rate of change to eliminate any error in the engine speed represented by the average speed data when the data representing the rate of change is output from said rate computing means; and
means for calculating interpolation data for the engine speed data on the basis of the rate of

change, the average speed data and the latest engine speed data during the period between the time one renewed average data is provided and the time next renewed average data is provided.

9. An apparatus for generating rotational speed data representative of the rotational speed of an internal combustion engine substantially as hereinbefore described with reference to, and as shown in the accompanying drawings.

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